

CHAPTER 8

STORMWATER BEST MANAGEMENT PRACTICES

22 February 2000

Chapter Eight - Stormwater Best Management Practices

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8.1 Overview

8.1.1 Introduction

To comply with federal law, the City of Lincoln is adopting a program to encourage the use of water quality Best Management Practices (BMPs) for new developments and re-development efforts. This chapter provides information and guidance regarding the selection and design of selected BMPs. Studies have documented that implementation of BMPs reduces pollutants in stormwater runoff and receiving waters. They can improve the water quality and environment of the community.

Urban runoff carries with it a wide variety of pollutants from diverse and diffuse sources. Pollutants associated with urban runoff often occur in higher concentrations than found in runoff prior to development. In addition, urban runoff can contain pollutants that are not naturally present in surface runoff from undeveloped land, such as organic pesticides, household solvents, and petroleum products. Runoff from undeveloped basins contains sediment particles, oxygen-demanding compounds, nutrients, metals, and other constituents. Once developed, pollutant loads increase because runoff volumes increase as do sources of the pollutants.

The phenomenon termed “first flush” has often been used to characterize urban runoff. First flush refers to the higher levels of initial concentrations of constituents that are washed off from the surface at the onset of a storm event. A typical pollutant concentration pattern during a storm event contains a relatively high concentration of contaminants during the first flush of runoff. However, depending on rainfall intensity, antecedent period length and conditions, deposition during the antecedent period, and surface characteristics, the affect of the first flush can be varied. After the first flush, the concentration typically drops substantially and fluctuates at a lower level for the remainder of the runoff event. A secondary “spike” in pollutant concentration can occur if a sudden burst of intense rain drives material off surfaces not completely cleaned by the initial runoff (Horner et al., 1994).

8.1.2 Structural and Nonstructural Best Management Practices (BMPs)

Studies such as the Nationwide Urban Runoff Program have documented concentrations of various pollutants in urban runoff (EPA, 1983). To reduce the concentrations and the loads of these pollutants that reach the receiving waters, a system of stormwater BMPs may be implemented. BMPs are defined as measures that function to either keep pollutants from entering stormwater or remove pollutants from stormwater. Various BMPs have been implemented throughout the United States. In general, they can be categorized as either structural or nonstructural. Structural BMPs can be thought of as constructed facilities designed to reduce runoff and/or passively treat urban stormwater runoff before it enters the receiving waters. Nonstructural BMPs consist of pollution prevention BMPs and source control BMPs. Both structural and nonstructural BMPs are used for erosion control during construction as well (UDFCD, 1992). A detailed discussion of sediment and erosion control is presented in Chapter 9.

The selection of the most appropriate BMPs for a given site or basin is largely dependent on whether development is in place or has yet to occur. In areas with existing development, nonstructural BMPs are the most cost-effective because retrofitting structural controls in a developed area can be expensive. Structural controls are more appropriate for new development and significant redevelopment, where they have been integrated into the planning of the infrastructure.

Because non-point source pollution is varied in nature and impact, no individual BMP may fit all situations. It must be tailored to fit the needs of particular sources and circumstances. An effective strategy for minimizing stormwater pollution loads is to use multiple BMPs (structural, nonstructural, and source controls). Multiple BMPs and combining BMPs in series can provide complementary water quality enhancement that minimizes pollutant loads being transported to the receiving waters.

8.2 General Water Quality Management Approach

8.2.1 General Planning and Design Guidelines

The following general planning and design guidelines for structural and nonstructural controls are recommended when developing a water quality control strategy:

- Promote natural infiltration of urban runoff by minimizing onsite impervious areas and preserving natural, broad drainageways.
- Minimize directly connected impervious areas by providing grassed or gravel buffer zones between impervious surfaces. Divert runoff from impervious areas to pervious surfaces before the flows enter surface drainageways.
- Locate structural BMPs in areas that avoid creating a nuisance and the need for increased maintenance.
- Provide multiple access to facilities to improve maintenance capabilities.
- Direct offsite stormwater flow around the onsite facilities.
- Revegetate and/or stabilize all areas disturbed by construction activities and all drainageways created as a part of the development.
- Ensure the plantings and grass cover are firmly established before the owner's obligation is released and maintenance efforts begin.

8.2.2 Effectiveness Of Management Measures

The effectiveness of many management measures was summarized in a 1992 report prepared by the Metropolitan Washington Council of Governments, entitled "A Current Assessment of Urban Best Management Practices." Some of the findings of this report include:

- Not all urban BMPs can reliably provide high levels of removal for both particulate and soluble pollutants. Effective BMPs include wet ponds, stormwater wetlands, multiple pond systems and sand filters. Infiltration BMPs are presumed to be effective in removing pollutants, but are not reliable given their poor longevity. Other BMPs, such as grassed swales, filter strips and water quality inlets, cannot provide reliable levels of pollutant removal until their basic design is significantly enhanced.
- The longevity of some BMPs is limited to such a degree that their widespread use is currently not encouraged. Of particular concern are the infiltration practices, such as basins, trenches and porous pavement. The poor longevity of these BMPs is attributable to a number of factors: lack of pretreatment, poor construction practices, application to infeasible sites, lack of regular maintenance, and in some cases, fundamental difficulties in basic design. Very often the life-spans of BMPs can be increased to acceptable lengths if local communities adopt enhanced designs and commit to strong maintenance and inspection programs.
- No single BMP option can be applied to all development situations and all BMP options require careful site assessment prior to design. Pond options are applicable to the widest range of development situations, but typically require a minimum drainage area. On the other hand, infiltration practices have very limited applications, requiring field verification of soils, water tables, slope and other factors.
- Several BMPs can have significant secondary environmental impacts, although the extent and nature of these impacts is uncertain and site-specific. Pond systems, which offer reliable pollutant removal and longevity, tend to be associated with the greatest number and strongest degree of secondary environmental impacts. Careful site assessment and design are often required to prevent stream warming, natural wetland destruction and riparian habitat modification.
- Relatively limited cost data exist to aid in the assessment of the comparative cost-effectiveness of urban BMP options. Presently, the selections of BMPs is based more on longevity, feasibility, and local design factors than on comparative cost. Maintenance costs may be significant and should be considered during the design process.
- In many cases, a systems approach to BMP design is warranted whereby multiple techniques for runoff attenuation, conveyance, pretreatment, and treatment are utilized.

- Several fundamental uncertainties still exist with respect to urban BMPs. These uncertainties include the toxicity of residuals trapped within BMPs; the interaction of groundwater and BMPs (both ponds and infiltration); and the long-term performance of urban BMPs. The USEPA has evaluated the benefits of water quality BMP's and their associated uncertainties and have determined that municipalities should encourage implementation of structural and non-structural BMP's.

Based on the above findings, it is clear how important it is to carefully plan and design BMPs on a site-specific basis. Success in applying any management practice depends on selecting the appropriate option for the control objectives, specific conditions at the site, proper implementation and maintenance.

8.3 Structural Best Management Practices

8.3.1 Pollutant Removal Mechanisms

Although runoff may contain many individual pollutants, they can, in general, be grouped into two categories: particulate and soluble. Often, pollutants such as metals and oxygen demand compounds become adsorbed or attached to particulate matter. Therefore, if the particulate matter is removed, so are the adsorbed or attached constituents.

There are four basic pollutant removal or immobilization mechanisms promoted by the BMPs described in this chapter. The following is an overview of each of them:

- Sedimentation - Particulate matter is, in part, settled out of urban runoff. Approximately 80 percent of metals in stormwater are attached or adsorbed to particles that are under 60 microns in diameter (i.e., fine silts and clays). Consequently, these particles can require long periods of time to settle out of suspension. With extended detention, however, the smaller particles can agglomerate into larger ones, thus removing a larger proportion of them through sedimentation.
- Filtering - Particulates can be removed from water by filtration. Filtration removes particles by attachment to small-diameter collectors such as sand.
- Infiltration - As surface runoff infiltrates or percolates into the ground, pollutant loads are removed or reduced in the runoff. Particulates are removed at the ground surface by filtration, and soluble contaminants can be adsorbed to the soil matrix as the runoff percolates into the ground. Soil characteristics such as permeability, cation exchange capacity, and depth to groundwater or bedrock limit the effectiveness of infiltration as a pollutant removal mechanism.
- Biological Uptake - Soluble constituents can be ingested or taken up from the water column and concentrated through bacterial action and phytoplankton growth. In addition, certain biological activities can reduce toxicity of some pollutants.

8.3.2 Structural BMP Selection

Selecting the appropriate BMP for a site depends on several factors, including:

- The permeability and type of soil underlying the BMP;
- The size of the tributary basin and the generated runoff volume in relation to the size of the BMP;
- The slopes and geometry of the site;
- The amount of base flow;
- The proximity of bedrock to the surface;
- The proximity to the seasonal high groundwater table to the surface;
- Tributary basin land uses; and
- The ability to handle high sediment loads.

8.3.3 Water Quality Control Volume

For many BMPs, combining the water quality facility with a flood control facility is practical and cost effective. Specifically, the water quality control volume (WQCV) that is recommended for control is the first half inch (0.5 inches) of runoff from the basin tributary to the BMP. For facilities that combine water quality control with flood control, the runoff from the design storms for the flood control criteria should be “stacked” on top of the water quality control volume. The water quality control volume should be detained over at least a 24-hour period, and preferably for longer.

8.3.4 Structural BMP Descriptions

This section gives information regarding the applicability, pollutant removal efficiencies, advantages, disadvantages, costs and maintenance considerations for structural BMPs that could be used within the City of Lincoln. Other structural BMP's may also be applicable for use in the City.

The structural BMPs covered in this chapter include:

- Extended Dry Detention Basins
- Retention (Wet) Ponds
- Constructed Wetlands
- Grassed Swales
- Filter Strips and Flow Spreaders
- Sand Filters
- Infiltration Trenches
- Porous Pavement
- Oil/Grit Separators
- Catch Basin Inserts

For each BMP, performance data are included to give a general idea of the pollution removal rates of different BMPs. These values are presented for comparison of BMPs only and are subject to wide variability when describing specific BMPs.

8.3.4.1 Extended Dry Detention Basins

Extended dry detention (ED) basins are designed to completely empty at some time after stormwater runoff ends. These are adaptations of the detention basins used for flood control. The primary difference is in outlet design; the extended basin uses a much smaller outlet that extends the retention time for more frequent events so that pollutant removal is facilitated. A 40-hour drain time for the WQCV is recommended to remove a significant portion of fine particulates and provide streambank erosion control (UDFCD, 1992; Schueler, 1987). The term "dry" implies that there is no significant permanent water storage (UDFCD, 1992).

Many designers encourage a two stage design in which the upper stage is dry except for infrequent large storm events and the lower stage is regularly inundated, with a volume equal to the runoff from the mean storm.

General applicability and experience with technique elsewhere

- a. Typical Applications
 - Significant areal requirement limits use; not typically a site-based BMP.
 - Retrofitting to established developments may be very difficult due to areal requirements.
 - Extended dry detention basins can reduce peak stormwater runoff rates while trapping sediment loads, particularly when used downstream from construction sites. Sediment from such high loads will need to be removed, however. ED basins can be used to improve runoff water quality from roads, parking lots, residential, commercial and industrial areas. Typically, they are used in conjunction with other onsite BMPs.
- b. Design Considerations (See Figures 8-1 through 8-3 for representative schematics)
 - Land requirement is typically 0.5 to 2.0 percent of drained area (UDFCD, 1992)
 - The volume of runoff detained should be based on 0.5 inches of runoff from the tributary area.

- Pilot channel should be constructed to minimize erosion control (alternately use turf if little low flow). Size such that any event runoff will overflow the low flow channel onto the pond floor.
 - Side slopes shall be no greater than 4:1 if mowed.
 - Inlet and outlet located to maximize flow length.
 - Design for full development upstream of control.
 - Rip-rap protection (or other suitable erosion control means) for the outlet and all inlet structures into the pond.
 - Use a water quality outlet that is capable of slowly releasing the WQCV over a 40-hour period. A perforated riser can be used in conjunction with a weir box opening above it to control for larger storm outflows. A sample outlet is illustrated in Figure 8-2. The number of perforations per row can be determined with the aid of Figure 8-3. This relationship is based on the rows being equally spaced vertically at 4 inches on center. Any other outlet that can meet the emptying time criteria should be acceptable (UDFCD, 1992).
 - One foot of freeboard above peak stage for top of embankment for design storm.
 - Emergency spillway designed to pass the 100-year storm event.
 - Maintenance access (< 8 % slope and approximately 10 feet wide).
 - Trash racks, filters or other debris protection on control and anti-vortex plates.
 - Insure no outlet leakage and use anti-seep collars.
 - Benchmark for sediment removal.
 - Two stage design (top stage - dry during the mean storm, bottom stage - inundated during storms less than the mean storm event.)
 - Top stage shall have slopes between 2% and 5% and a depth of 2 to 5 feet.
 - Design as off-line pond to bypass larger flows.
 - Design as sediment settling basin for pretreatment of the larger particles.
 - Addition of a small wetland marsh or ponding area in the basin's bottom may enhance soluble pollutant removal, however storms may flush out trapped sediments and minimize this benefit.
 - The facility must also meet the criteria provided in Chapter 6 Storage Facilities.
- c. Other Experiences with BMP
- Extended dry detention basins have performed well in sediment and associated pollutant removal efficiencies. They also prevent streambank erosion. Problems noted include clogging of the outlet and detention times significantly lower than design (Galli, 1992).

Reported pollutant removal efficiencies

- Reported data

EPA, 1986; Grizzard et al., 1986; Whipple and Hunter, 1981:

Suspended Solids	50-70%
Total Phosphorus	10-20%
Total Nitrogen	10-20%
Zinc	30-60%
Bacteria	50-90%
Lead	75-90%

Galli, F.J., 1992:

Lead	62%
Zinc	57%

- For soluble pollutants (e.g. phosphorous, nitrogen, zinc), the removal performance appears to be more consistent than for retention ponds or wetlands, although the latter have higher maximum removal rates. Removal rates for less soluble constituents are somewhat less than those for retention ponds or wetlands (Urbonas and Stahre, 1993).

Stormwater BMPs

- Due to the wide range of variability for pollutant removal, a conservative estimate near the low end of the ranges reported should be assumed.

Advantages

- Moderate to high removal of particulates and suspended heavy metals.
- Infiltration and resultant recharge to ground water is minimal compared to infiltration type BMPs, therefore the risk of direct introduction of contaminants to ground water is also minimal.

Disadvantages

- a. Human Risk, Public Safety and Potential Liability
- b. Environmental Risk and Implications
 - Possible habitat destruction
 - High ground water levels may inundate the basin and outlet (use retention ponds if this is the case); ground water mounding may occur with slow-draining or silt-clogged soils.
 - Thermal modification to downstream waters should be minimal (Schueler, 1987)
- c. Other
 - Will likely have negative aesthetics unless a lower-stage basin is used.
 - Can become a trash dump if not maintained.
 - Potential breeding grounds for mosquitos and other insects unless a balanced habitat is established.
 - Aesthetics; must factor in debris and sediment accumulation and removal, as well as overall design integration with site.

Maintenance/monitoring/enforcement considerations

- a. Reliability and Consistency over Time
 - Exfiltration will tend to decrease over time as the bottom becomes clogged with sediment; this may be a positive factor in preventing ground water contamination.
- b. Routine and Non-routine Maintenance
 - Cleanup of debris and trash, pest and overgrowth control, erosion repairs, inspect for structural damage to outlets, clogging of outlet.
 - A five to ten year sediment cleanout cycle is recommended (Schueler, 1987).
- c. Sustainability of Maintenance or Program Management
 - Regular maintenance and sediment cleanout are not technically difficult; long-term management should not be problematic.

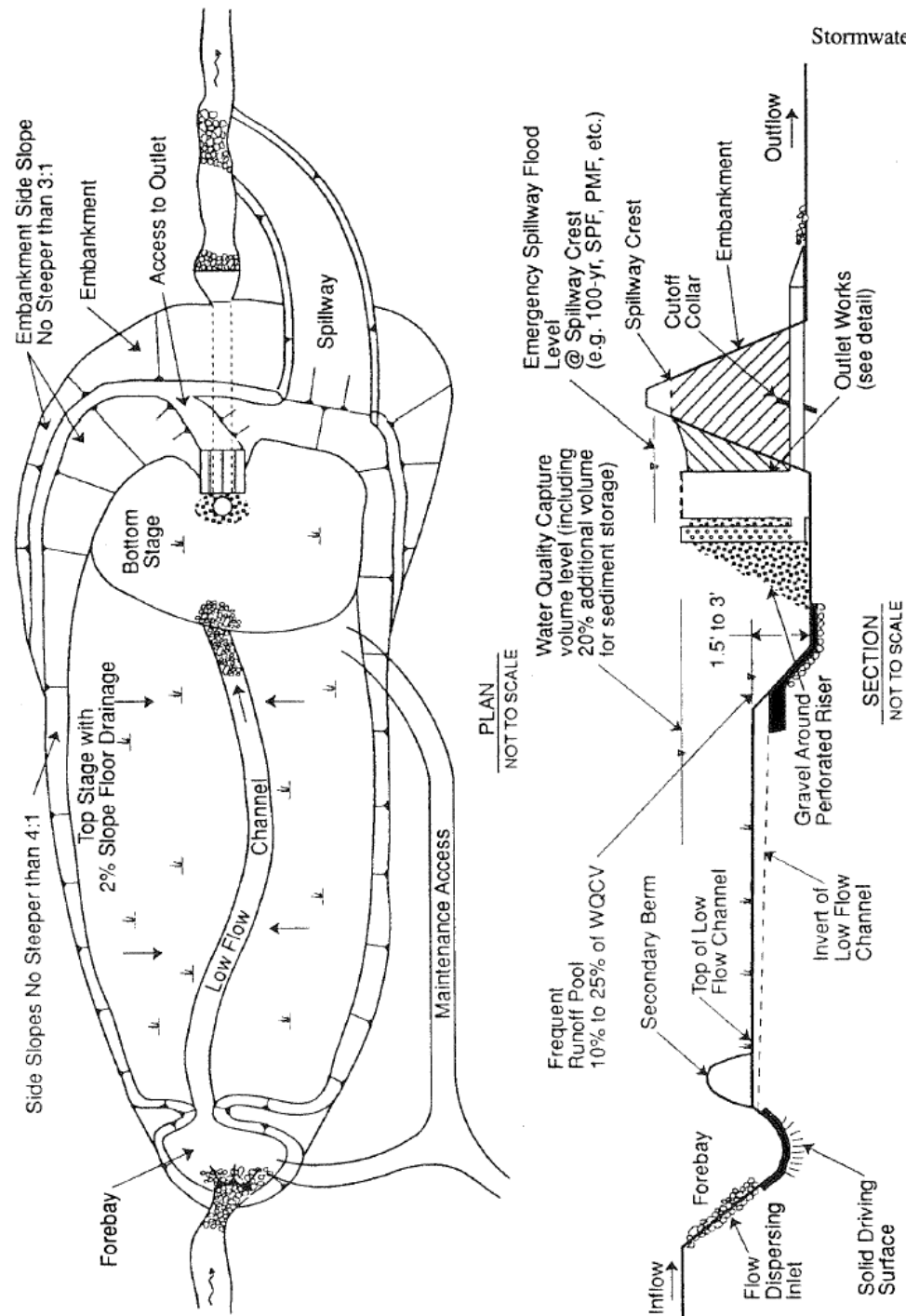
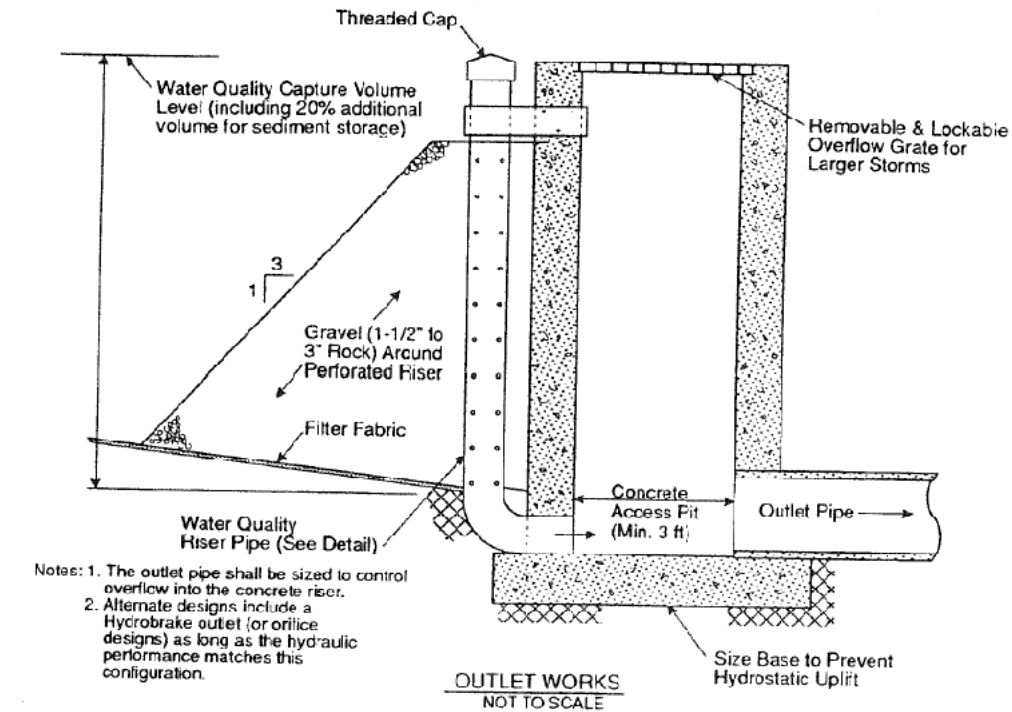
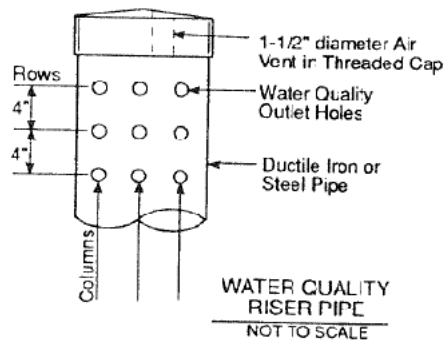


Figure 8-1 Extended Dry Detention Basin

Source: Denver Urban Drainage and Flood Control District, 1992



- Notes: 1. Minimum number of holes = 8
2. Minimum hole diameter = 1/8" dia.



Maximum Number of Perforated Columns				
Riser Diameter (in.)	Hole Diameter, in.			
	1/4"	1/2"	3/4"	1"
4	8	8	--	--
6	12	12	9	--
8	16	16	12	8
10	20	20	14	10
12	24	24	18	12
Hole Diameter (in.)		Area of Hole (in. ²)		
1/8		0.013		
1/4		0.040		
3/8		0.110		
1/2		0.196		
5/8		0.307		
3/4		0.442		
7/8		0.601		
1		0.785		

Figure 8-2 Water Quality Outlet for Extended Dry Detention Basin

Source: Denver Urban Drainage and Flood Control District, 1992

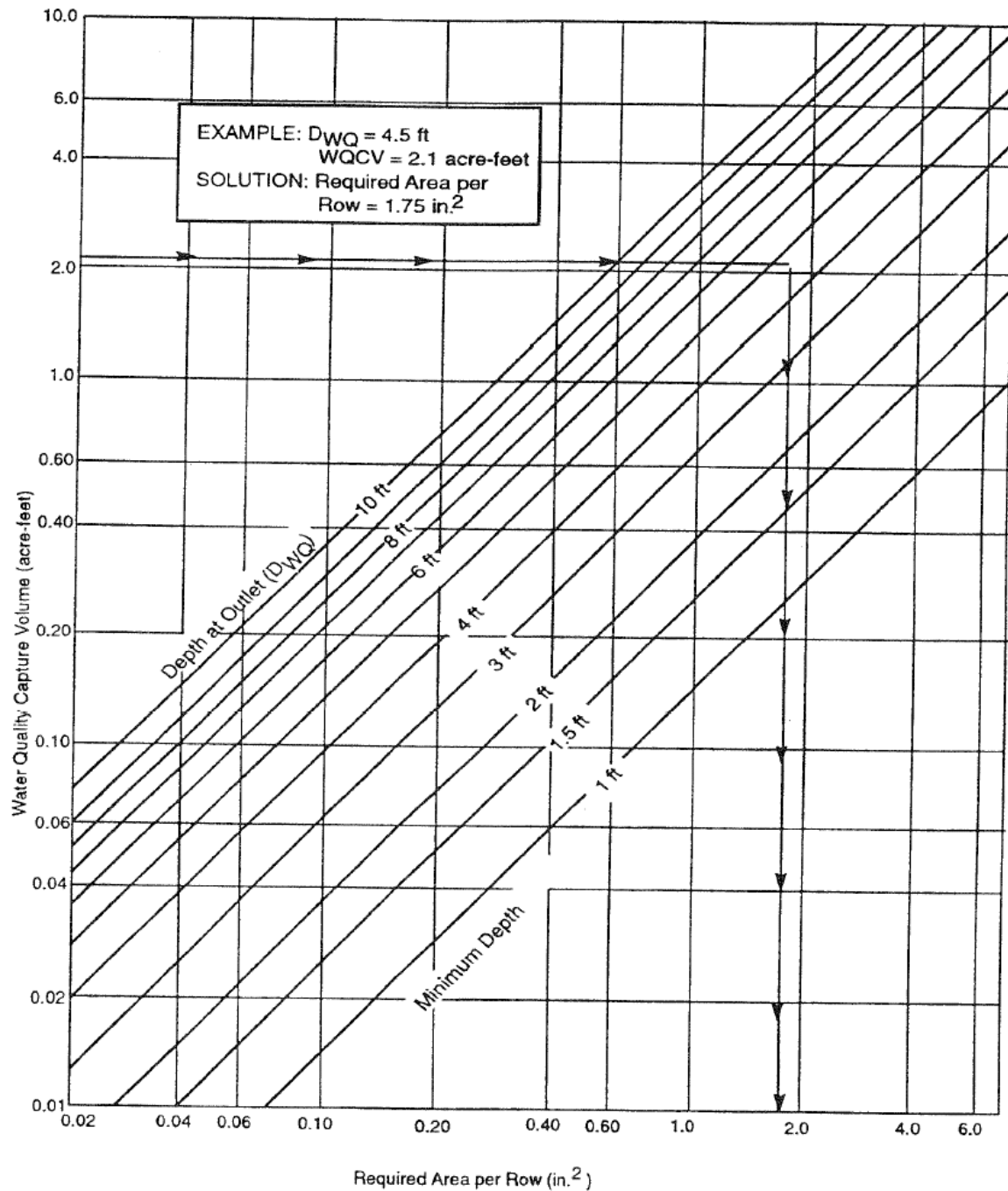


Figure 8-3 Water Quality Outlet Sizing for Extended Dry Detention Basin with 40 Hour Drain Time of the Capture Volume

Source: Denver Urban Drainage and Flood Control District, 1992

8.3.4.2 Retention (Wet) Ponds

A retention pond is designed to not completely drain as in the dry basin design. A permanent pool of water is replaced in part by stormwater during an event. For water quality purposes, the design is such that the WQCV is released over 12 to 24 hours, but the hydraulic residence time (HRT) for the permanent pool volume is two weeks or longer. Reduction of volume in the permanent pool is through evapotranspiration and infiltration only. A dry weather base flow may be required to maintain the permanent pool (UDFCD, 1992).

General applicability and experience with technique elsewhere

- a. Typical Applications
 - Typically not a site-based BMP, but retention ponds are effective in most settings where adequate open area exists. Due to the area required, it is difficult to retrofit to a completely developed watershed.
 - Since evaporation can quickly dry up base flows, retention ponds work best in areas with low ET rates and/or non-arid climates.
 - Wet retention ponds can reduce peak stormwater runoff rates while trapping sediment loads, as well as provide some biological uptake of nutrients. They can be used downstream from construction sites, but sediment removal is difficult. They can be used to improve runoff water quality from roads, parking lots, residential, commercial and industrial areas. Typically, they are used in conjunction with other onsite BMPs.
- b. Design Considerations (See Figures 8-4 through 8-6 for representative schematics)
 - Minimum length to width ratio of 3:1 (preferably wedge shaped expanding outward toward the outlet). Irregular shorelines for larger ponds provide visual variety.
 - Inlet and outlet located to maximize flow length. Use baffles to increase flow length if needed.
 - Minimum depth of permanent pool 2 to 3 feet, maximum depth of 9 to 10 feet. Average depth should be 3 to 6 feet.
 - Design for full development upstream of control.
 - Side slopes shall be no greater than 4:1.
 - Rip-rap protection (or other suitable erosion control means) for the outlet and all inlet structures into the pond. Individual boulders or baffle plates can work for this.
 - Minimum drainage area of 10 acres. Land requirement is typically 0.5 to 2.0 percent of drained area (UDFCD, 1992).
 - Use a water quality outlet that is capable of slowly releasing the WQCV over a 12-hour period. A perforated riser can be used in conjunction with a weir box opening above it to control for larger storm outflows. A sample outlet is illustrated in Figure 8-5. The number of perforations per row can be determined with the aid of Figure 8-6. This relationship is based on the rows being equally spaced vertically at 4 inches on center. Any other outlet that can meet the emptying time criteria should be acceptable (UDFCD, 1992).
 - Emergency drain; i.e. sluice gate, drawdown pipe; capable of draining within 24 hours.
 - Trash racks, filters, hoods or other debris control on riser.
 - Maintenance access (< 8 % slope and 10 feet wide).
 - Benchmark for sediment removal.
 - Design for multi-function as flood control and extended detention.
 - Sediment forebay for larger ponds (often designed for 5 to 15 percent of total volume). Forebay should have separate drain for de-watering. Grass biofilters for smaller ponds.
 - Incorporating a wetland design or wetland vegetation into the pond can increase contaminant removal rates. This may also encourage wildlife habitation which can help in mosquito and pest control.
 - If fast draining soils are present, a liner may be needed to sustain baseflow; conversely, if bedrock is present and needs to be excavated, construction costs may become very high.
 - The facility must also meet the criteria provided in Chapter 6 Storage Facilities.

c. Other Experiences with BMP

- Wet retention ponds are generally more effective at removing nutrient loadings than dry basins; their use is encouraged where nutrient loads are a major contributor to water quality problems (Hartigan, 1989)
- According to the NURP study, basins which exhibit high removal efficiencies are sized such that the mean storm displaces only about 10% of the available volume, and overflow rates (mean runoff rate/basin surface area) are a small fraction of the median particle settling velocity (EPA, 1993). The study concluded that retention ponds are capable of providing very effective removal of pollutants in urban runoff.

Reported pollutant removal efficiencies

- Reported data

EPA, 1983:

Suspended Solids	91%
Total Phosphorus	0-80%
Total Nitrogen	0-80%
Zinc	0-70%
Lead	9-95%
BOD	0-69%

Yousef, Y.A., et al. 1986:

A well-oxygenated pond with minimum organic debris appears to provide the environment for improved removal efficiencies of nutrients and selected heavy metals. Also, it was concluded that slower infiltration rates and increased mean residence time favor retention of metals within the sediments. There was no evidence of metals migration within the sediments or that a contamination hazard exists to nearby surface or ground water.

Dissolved Lead	54.5%
Particulate Lead	95.1%
Dissolved Zinc	88.3%
Particulate Zinc	96.2%
Dissolved Copper	49.7%
Particulate Copper	77.0%
Dissolved Phosphorous	90.1%
Particulate Phosphorous	11.4%
Organic Nitrogen	11.0%
Ammonia	81.6%
Nitrates + Nitrites	86.5%

Hartigan 1989:

Reported expected removal rates of 40 - 60% for phosphorous and 30 - 40% for nitrogen. Additionally, a minimum Basin area/tributary area ratio of 1% is recommended for high removal rates; 3% for poorly draining soils.

Advantages

- Cost-effective for larger tributary watersheds
- Moderate to high removal rates of many urban pollutants
- Creates wildlife habitat

Stormwater BMPs

- Provides recreation, aesthetics, open space areas
- More efficient sedimentation than dry basin, since outlet is above the basin bottom, leaving a 'dead zone' to trap sediment
- Infiltration and resultant recharge to ground water is minimal compared to infiltration type BMPs, therefore the risk of direct introduction of contaminants to ground water.

Disadvantages

- a. Human Risk, Public Safety and Potential Liability
- b. Environmental Risk and Implications
 - Attract waterfowl, which may increase downstream nutrient loading and bacteria.
 - Inadequate base flow can cause very high concentrations of salts, nutrients, and algae through evaporation, resulting in significant downstream loadings from smaller events.
 - Possible low DO effluent, stream warming, trophic shifts, habitat destruction, loss of upstream channels.
 - Large events or low dissolved oxygen content can cause mixing or resuspension of deposited sediments, increasing turbidity and metals concentrations.
- c. Other
 - Higher cost than conventional stormwater detention.
 - Difficult sediment removal.
 - Floating litter, scum and algal blooms, odors, insects.
 - Bottom of pool may need to be lined to maintain permanent pool in well-draining conditions.
 - Wet retention ponds have greater storage capacity requirements than dry ED basins, resulting in higher capital costs.
 - Large basins may require a dam safety permit.

Maintenance/monitoring/enforcement considerations

- a. Reliability and Consistency over Time
 - May be more efficient over time due to increased vegetation providing enhanced nutrient and metals removal rates
- b. Routine and Non-routine Maintenance
 - Sediment to be removed when 20% of storage volume of the facility is filled (design storage volume must account for volume lost to sediment storage).
 - No woody vegetation shall be allowed on the embankment without special design provisions.
 - Other vegetation over 18 inches high shall be cut unless it is part of planned landscaping.
 - Debris shall be removed from blocking inlet and outlet structures and from areas of potential clogging.
 - The control shall be kept structurally sound, free from erosion, and functioning as designed.
 - Control of scum and algal blooms, odors, insects.
 - The site should be inspected and debris removed after every major storm.
- c. Sustainability of Maintenance or Program Management
 - Funds must be budgeted for routine and non-routine maintenance, particularly considering the high cost of sediment removal. For this reason, public rather than private maintenance is preferred (Schueler, 1987).

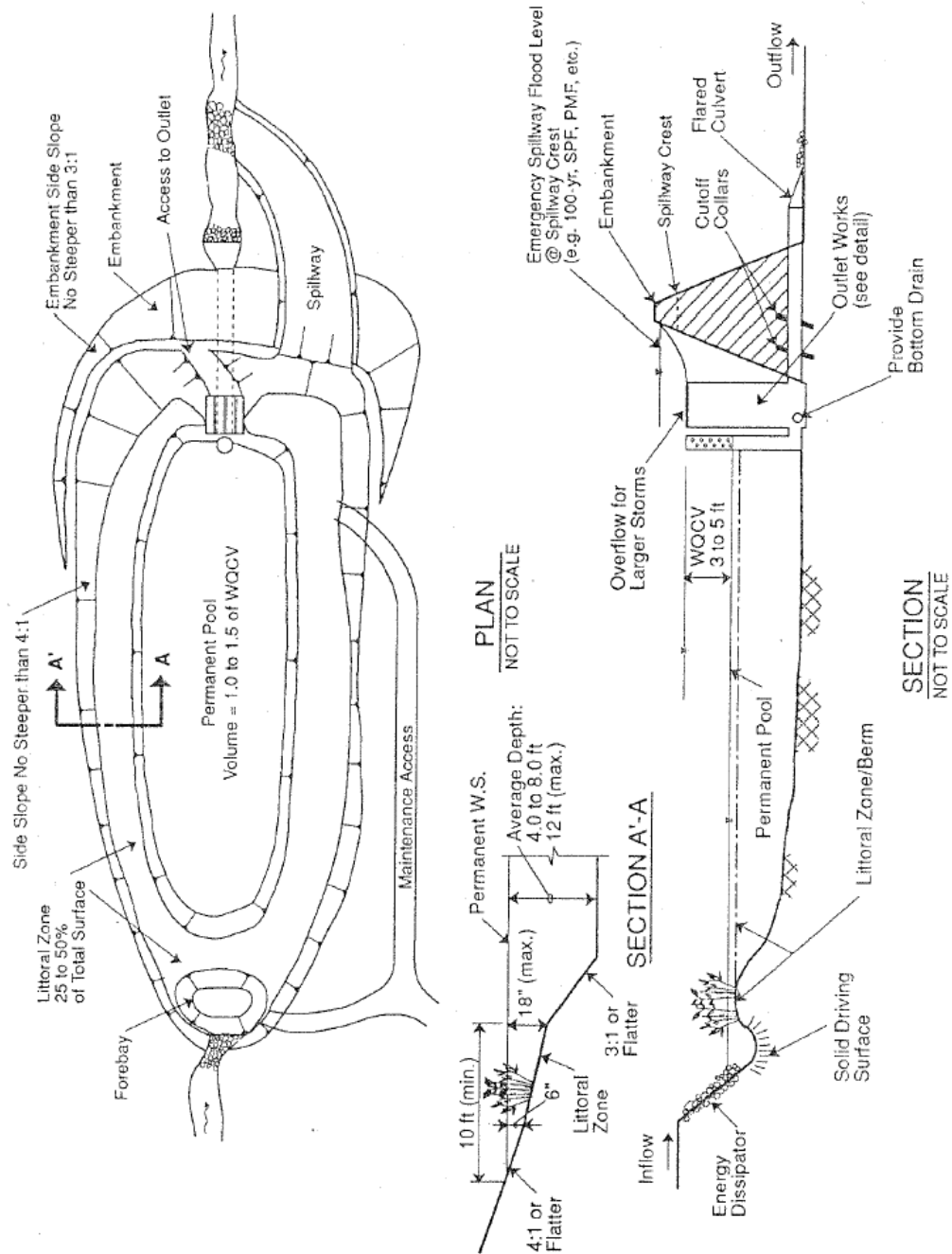
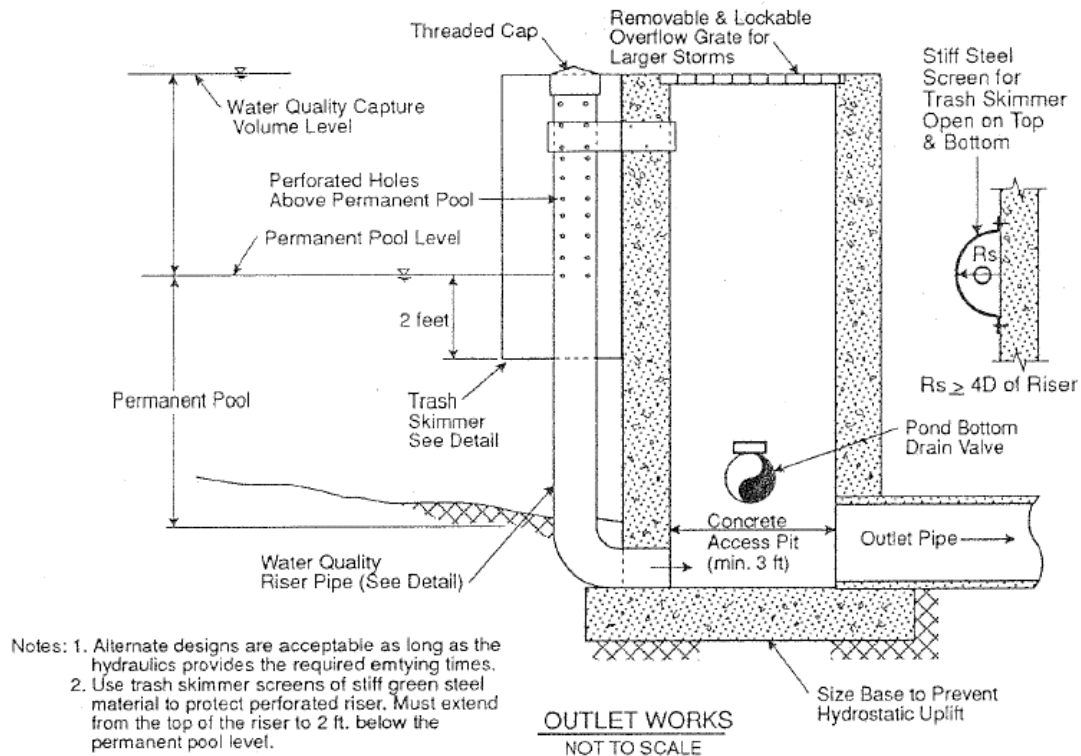
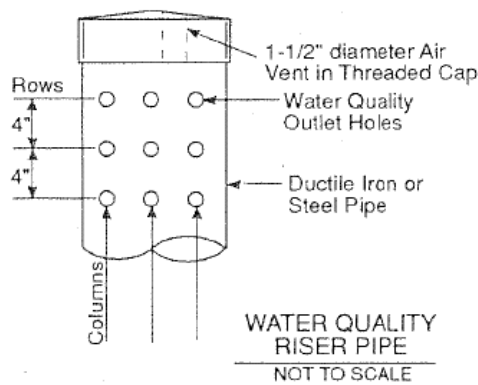


Figure 8-4 Retention (Wet) Pond

Source: Denver Urban Drainage and Flood Control District, 1992



- Notes: 1. Minimum number of holes = 8
2. Minimum hole diameter = 1/8" Dia.



Maximum Number of Perforated Columns				
Riser Diameter (in.)	Hole Diameter, inches			
	1/4"	1/2"	3/4"	1"
4	8	8	--	--
6	12	12	9	--
8	16	16	12	8
10	20	20	14	10
12	24	24	18	12
Hole Diameter (in.)		Area (in. 2)		
1/8		0.013		
1/4		0.049		
3/8		0.110		
1/2		0.196		
5/8		0.307		
3/4		0.442		
7/8		0.601		
1		0.785		

Figure 8-5 Water Quality Outlet for Retention Pond

Source: Denver Urban Drainage and Flood Control District, 1992

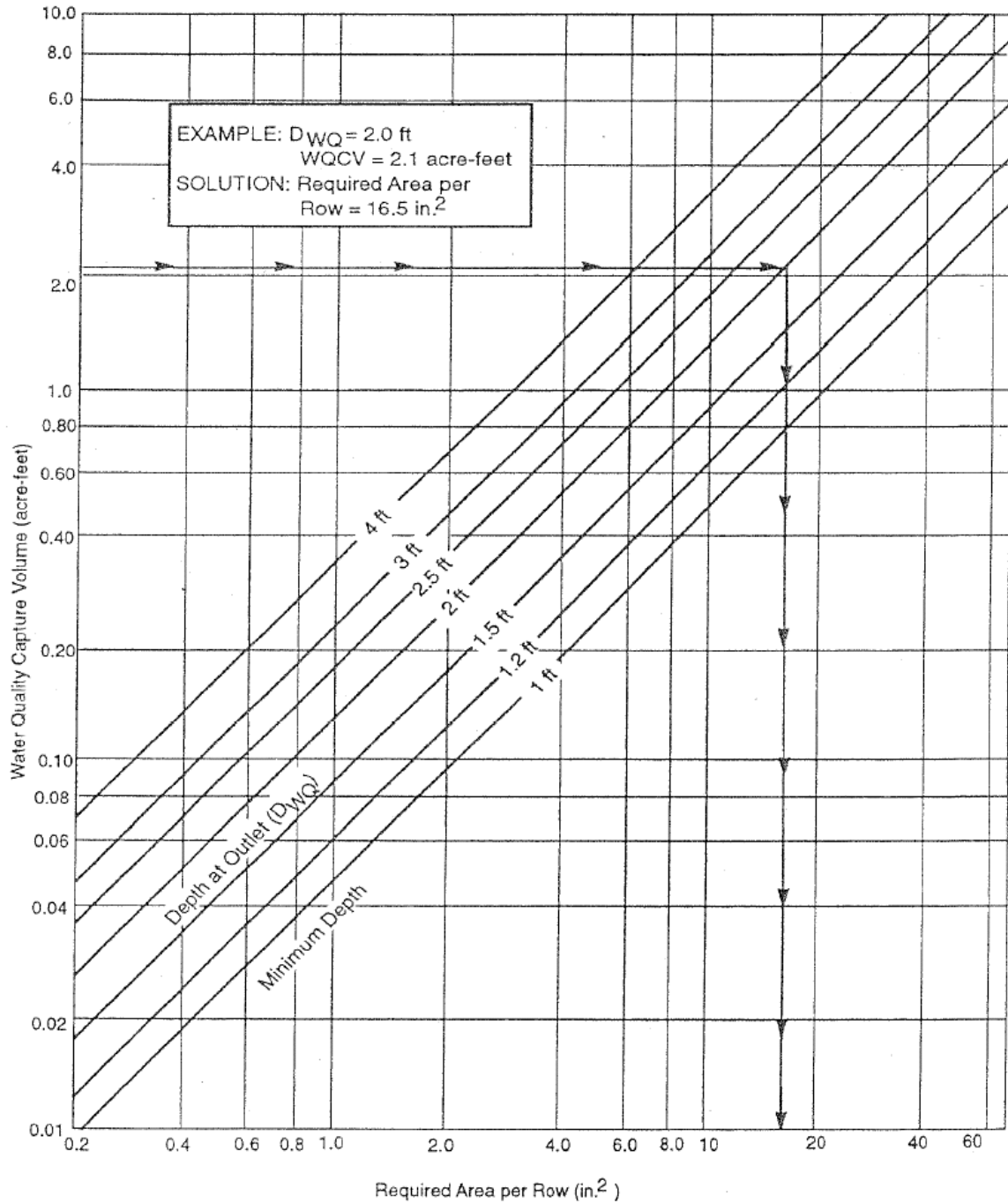


Figure 8-6 Water Quality Outlet Sizing for Retention Pond with 12 Hour Drain Time of the Capture Volume

Source: Denver Urban Drainage and Flood Control District, 1992

8.3.4.3 Constructed Wetlands

Constructed wetlands can take the form of very shallow retention ponds or wetland-bottomed channels. A perennial base flow is needed to encourage the growth of wetland species such as rushes, willows, cattails, and reeds. These slow runoff and promote settling and biological uptake. "Pocket" wetlands are typically under a tenth of an acre in size, serving developments of 10 acres or less. These are usually less reliable and efficient than larger wetlands.

General applicability and experience with technique elsewhere

- a. Typical Applications
 - Wetland basins can be used as a follow-up BMP in a watershed, or as an onsite facility if the owner can provide sufficient water. Flood control measures may be instituted above the wetland basin.
 - Retrofitting to established developments may be very difficult due to areal requirements.
 - Arid climates or high ET rates can make maintenance of the required base flow difficult. Also, short growing seasons may inhibit vegetation growth and propagation.
 - Wetland bottom channels can be used in two ways: first, a wetland can be established in a man-made channel and can act as both a conveyance facility and a water quality enhancement facility. Perhaps the more effective option is to locate the channel downstream of a stormwater detention facility that will remove much of the sediment load. The channel then provides better quality water to the receiving water body. The detention facility should have at least a 24 hour drain period for the storm event.
- b. Design Considerations (See Figures 8-7 through 8-8 for representative schematics)
 - A water budget analysis is needed to ensure the adequacy of the base flow. Also, loamy soils are needed to permit rooting of plants. A near-zero longitudinal slope is required.
 - Designed for an extended detention time of 24 hours.
 - Surface area of the wetland should account for a minimum of 3 percent of the area of the watershed draining into it.
 - The length to width ratio should be at least 2 to 1.
 - A soil depth of at least 4 inches shall be used for shallow wetland basins.
 - Approximately 75 percent of the wetland should have water depths less than 12 inches, and 25 percent of the wetland should have depths ranging from 2 to 3 feet. Of the 75 percent of the wetland that should be 12 inches deep or less, it is recommended that approximately 25 percent range from 6 inches deep to 12 inches deep, and that the remaining 50 percent be 6 inches or less in depth.
 - The deeper area of the wetland should include the outlet structure so outflow from the basin is not interfered with by sediment buildup.
 - A forebay should be established at the pond inflow points to capture larger sediments and be 4 to 6 feet deep. Direct maintenance access to the forebay should be provided with access 15 feet wide minimum and 5:1 slope maximum. Sediment depth markers should be provided.
 - If high water velocity is a potential problem, some type of energy dissipation device should be installed.
 - The designer should maximize use of pre- and post-grading pondscaping design to create both horizontal and vertical diversity and habitat.
 - A minimum of 3 aggressive wetland species (obligate wetland species) of vegetation should be planted 2 feet on center within the area of wetland that contains approximately 6 inches of water or less.
 - Three additional wetland species (facultative wetland species) of vegetation should be planted in clumps of 5 in saturated soil outside of the obligate wetland area with a spacing of 3 feet on center.
 - Wetland mulch, if used, should be spread over the high marsh area and adjacent wet zones (-6 to +6 inches of depth) to depths of 3 to 6 inches.
 - A minimum 25-foot buffer, for all but pocket wetlands, should be established and planted with riparian and upland vegetation (50-foot buffer if wildlife habitat value required in design).
 - Surrounding slopes should be stabilized by planting in order to trap sediments and some pollutants and prevent them from entering the wetland.

- A written maintenance plan should be provided and adequate provision made for ongoing inspection and maintenance, with more intense activity for the first three years after construction.
 - The wetland should be maintained to prevent loss of area of ponded water available for emergent vegetation due to sedimentation and/or accumulation of plant material.
 - To minimize maintenance as much as possible, it is recommended that wetland basins be installed on stabilized watersheds and not be used for sediment control.
 - Complex topography can be maintained by bioengineering methods (such as fascines) or straw bales and geotextile rolls.
 - It is recommended that the frequently flooded zone surrounding the wetland be located within approximately 10 to 20 feet from the edge of the permanent pool.
 - The wetland should be designed to allow slow percolation of the runoff through the substrate (add a layer of clay for porous substrates).
 - The depth of the forebay should be in excess of 3 feet and contain approximately 10 percent of the total volume of the normal pool.
- c. Other Experiences with BMP
- Wetlands for storm water treatment have been used for 10 to 15 years. Estimates for removal rates vary widely in the literature, probably due to a lack of data that would produce design protocols. Some higher removal rates may be the result of testing in experimental wetlands and from wastewater treatment sites which have much higher concentrations of BOD and nutrients.
 - Pollutant removal efficiencies appear to vary greatly depending on design and environment.

Reported pollutant removal efficiencies

- Reported data

USGS, 1986 (based on 13 sampled runoff events in Orlando, Florida):

Suspended Solids	40-94%
Total Nitrogen	0-21%
Zinc	(-29)-82%
Lead	27-94%
BOD	18%

Lakatos and McNemer, 1987:

Total Phosphorus	(-4)-90%
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Wright Water Engineers, 1991:

Manganese	36-77%
Suspended Solids	29-92% (71% average on eight projects)

- Claims of high removal rates of nutrients from stormwater are not substantiated by data; these claims may be based on data from experimental wetlands and from wastewater removal rates, where influent concentrations are much higher.
- Nitrification and Denitrification are dependent on many variables, with detention time perhaps the most significant; Shaver (1994) recommends 14 days.

Stormwater BMPs

Advantages

- Aesthetics, wildlife habitat, erosion control, pollutant removal

Disadvantages

- a. Environmental Risk and Implications
 - Possible stream warming, natural wetlands alteration
 - Salts and scum may accumulate and be flushed out with a major storm event.
 - Possible breeding ground for pests, mosquitos. However, the Maryland study (Galli, 1992) found no mosquito larvae at any of nine sites surveyed, and there is evidence that this is the norm for constructed wetlands.
 - Effectiveness at removing nitrogen and some forms of phosphates is questionable.
- b. Other
 - Need for periodic sediment removal to maintain proper distribution of growth zones and water movement.

Maintenance/monitoring/enforcement considerations

- a. Reliability and Consistency over Time
 - Difficult to determine, but with proper design and maintenance the wetland should perform well for an indefinite period of time.
- b. Routine and Non-routine Maintenance
 - Proper depth and spatial distribution of growth zones must be maintained
 - Remove unwanted vegetation, debris and litter, accumulated sediment and organic muck.
- c. Sustainability of Maintenance or Program Management
 - Maintenance is generally greatest during the first three years in order to establish vegetation.

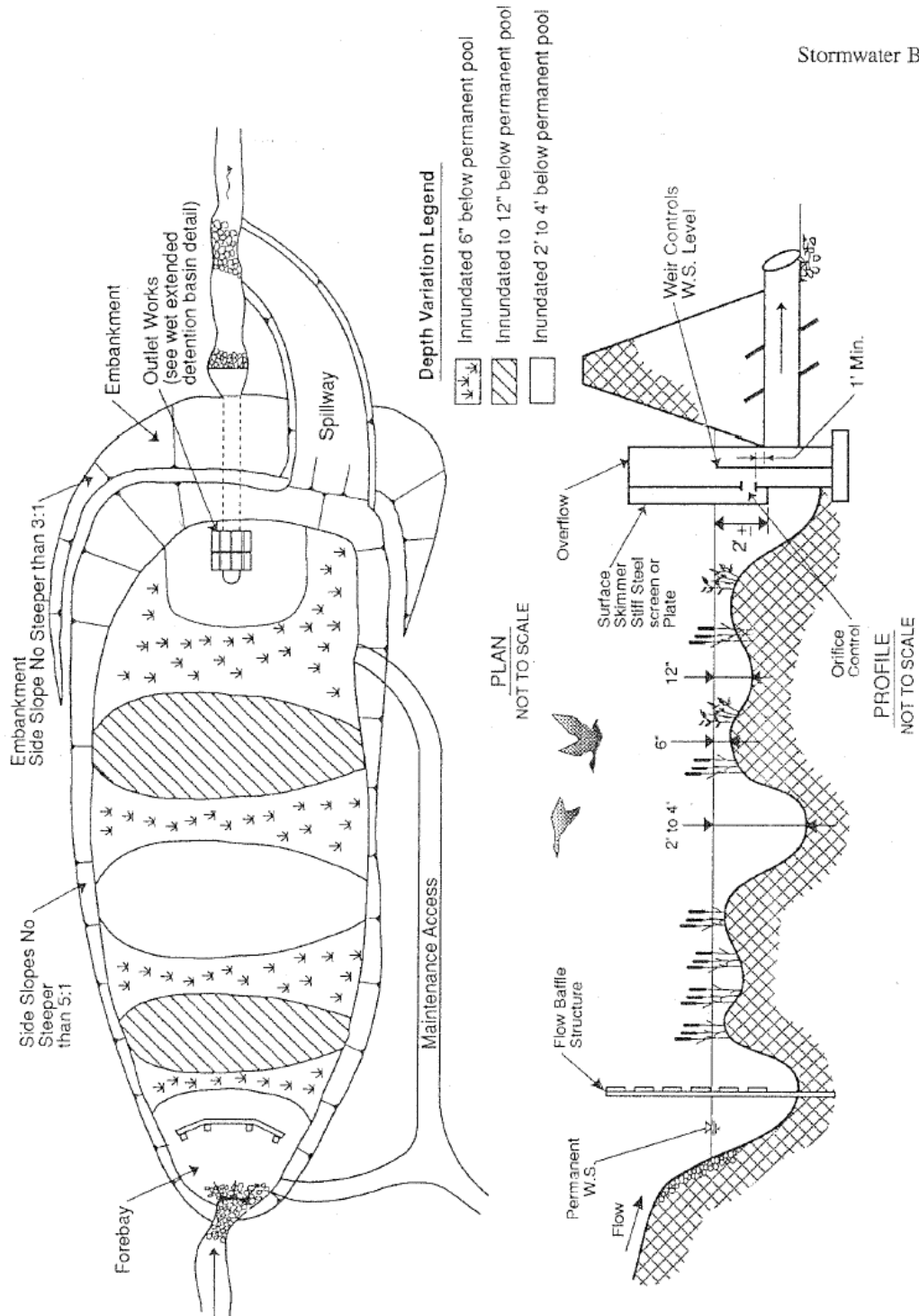


Figure 8-7 Plan and Profile of Wetland Pond

Source: Denver Urban Drainage and Flood Control District, 1992

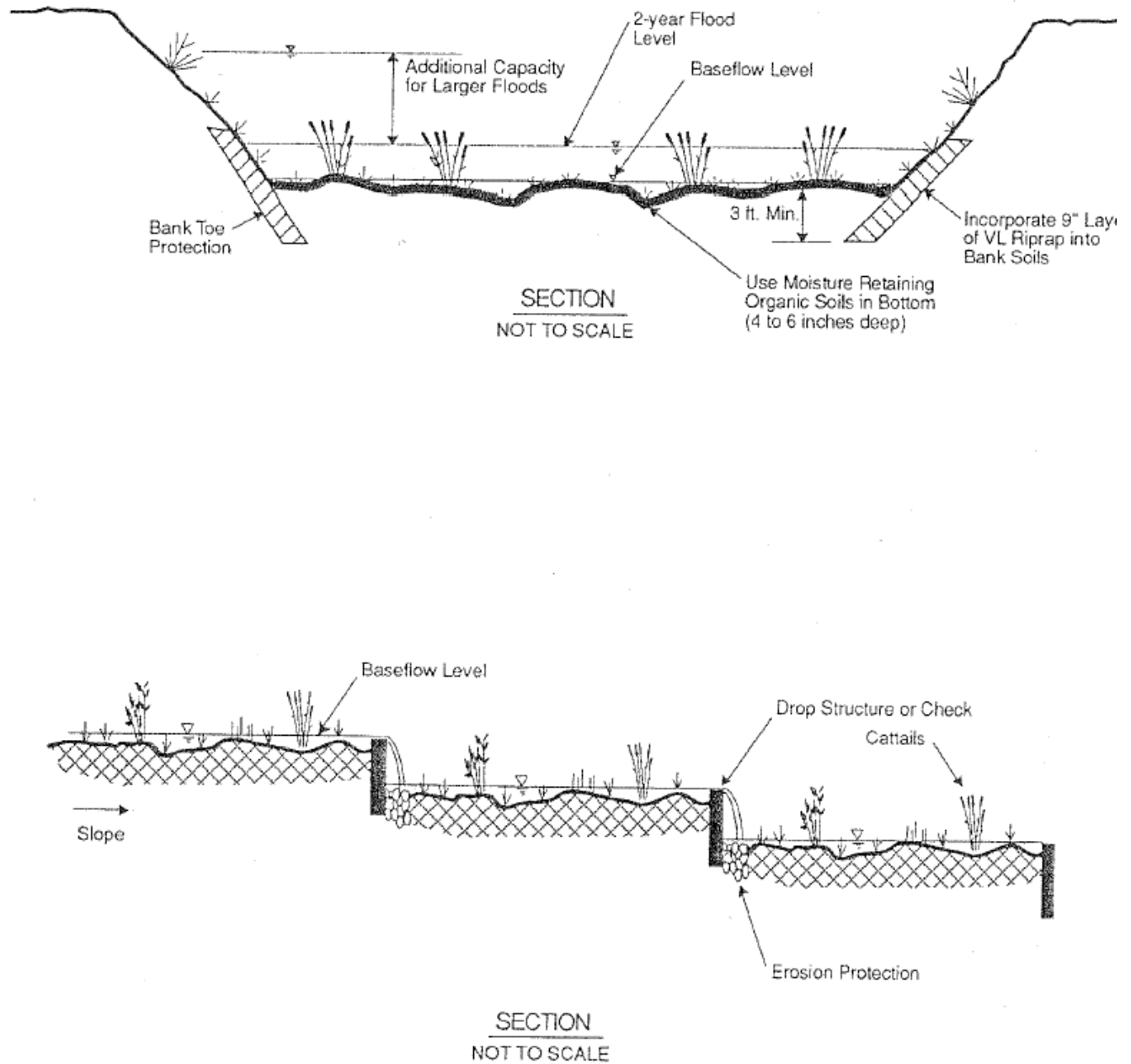


Figure 8-8 Plan and Section of Wetland Channel

Source: Denver Urban Drainage and Flood Control District, 1992

8.3.4.4 Grassed Swales

Grassed swales are densely vegetated drainageways with low-pitched sideslopes that collect and slowly convey runoff. The emphasis is on slow, shallow flow that encourages sedimentation and discourages erosion. They are set lower than the surrounding ground level, allowing runoff to enter the swales over grassy, shallow banks. Check dams may be used in conjunction with the swales to further slow the runoff. If base flow is present, wetland vegetation may also develop.

General applicability and experience with technique elsewhere

- a. Typical Applications
 - Swales are often used to collect overland flow from impervious areas such as parking lots, buildings and roadways, as well as semi-pervious areas such as grass filter strips and residential yards. They are often presented as an option to curb-and-gutter systems in order to reduce peak flow rates and reduce pollutant loading downstream. A follow-up BMP will be required to enhance water quality.
- b. Design Considerations (See Figures 8-8 for representative schematic)
 - Generally well adapted for sites with ground slopes up to 3 or 4 percent, and not over 6 percent. The longitudinal slope of the swale should be less than 1 percent.
 - Limited to runoff velocities less than 1.5 to 2.5 ft/s.
 - Maximum design flow depth to be approximately 3 foot.
 - Swale cross-section should have side slopes of 4:1 (h:v) or flatter.
 - Underlying soils should have a high permeability.
 - Swale area should be tilled before grass cover is established.
 - Dense cover of a water tolerant, erosion resistant grass should be established over swale area.
 - As a BMP, grassed swales are best suited to residential or institutional areas where percentage of impervious area is relatively small.
 - Check dams can be installed in swales to promote additional infiltration. Recommended method is to sink a railroad tie halfway into the swale. Riprap stone should be placed on the downstream side to prevent erosion.
 - The NURP study concluded that adequate residence times are key to significant pollutant removal, although parameters were not determined.
- c. Other Experiences with BMP
 - A New Hampshire NURP project showed heavy metal reductions of approximately 50% and COD, nitrate, and ammonia reductions around 25%.
 - Primarily an infiltration practice, so that soluble pollutants may be directed to the ground water.
 - Removal efficiencies vary widely; the reasons for this are not well understood.

Reported pollutant removal efficiencies

- Reported data

Whalen and Callum, 1988:	
TSS	80%
Oakland, P.H., 1983:	
Cadmium, total	56%
Cadmium, dissolved	42%
Zinc, dissolved	47%
Copper, dissolved	53%
Lead, dissolved	63%

Schueler, et al., 1992 (for low gradient swales with check dams):

Stormwater BMPs

TSS	60-80%
Total Phosphorus	20-40%
Total Nitrogen	20-40%
BOD	20-40%
Metals	60-80%

- The key to pollutant removal may be soils with high infiltration rates and flow velocities of less than 0.5 ft/sec. (Urbonas and Stahre, 1993). This may be inappropriate for areas with high ground water tables.
- Filtration, adsorption, and ion exchange may occur in the underlying soils, reducing the potential for ground water contamination.

Advantages

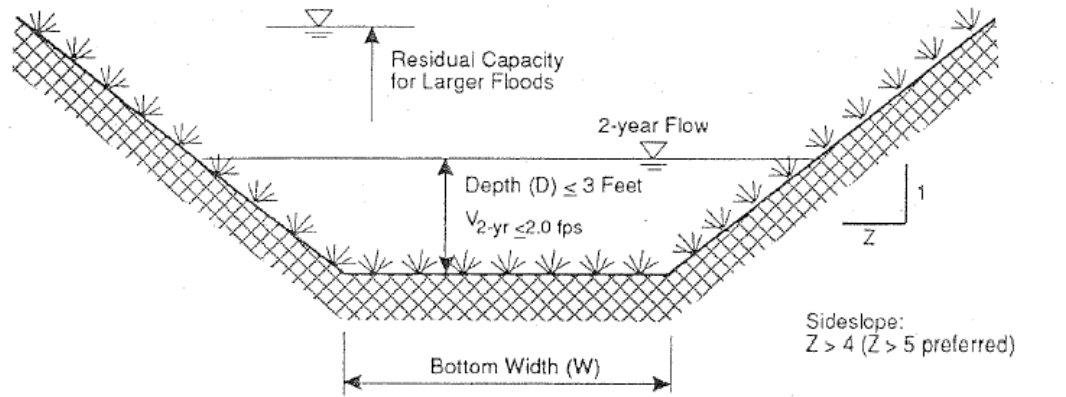
- Aesthetics.
- Effective in reducing runoff in small storm events where other BMPs are less effective.
- Can be used to limit the extent of directly connected impervious areas.

Disadvantages

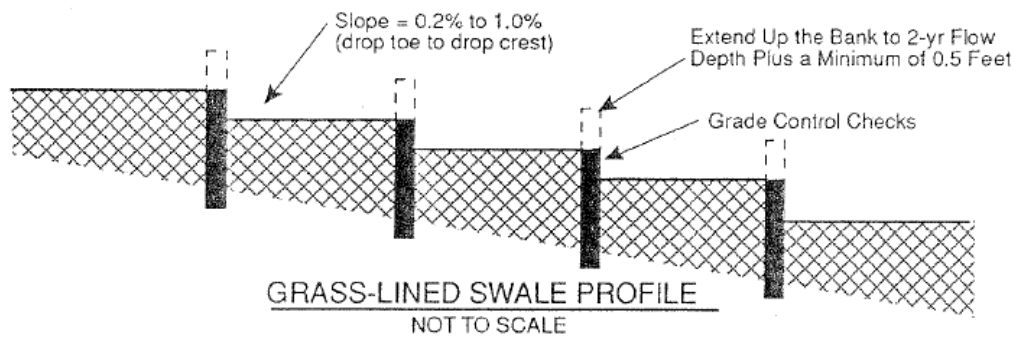
- a. Human Risk, Public Safety and Potential Liability
 - Potential for soggy yards, mosquito breeding, and more right-of-way requirement than for equivalent storm sewers.
- b. Environmental Risk and Implications
 - Particularly with small storm events, the primary removal mechanism is infiltration; in areas of high ground water vulnerability, this may not be a good option.
- c. Other
 - Effectiveness is limited by infiltration capacity of soils; conversely, well-draining soils may direct polluted runoff directly to ground water.

Maintenance/monitoring/enforcement considerations

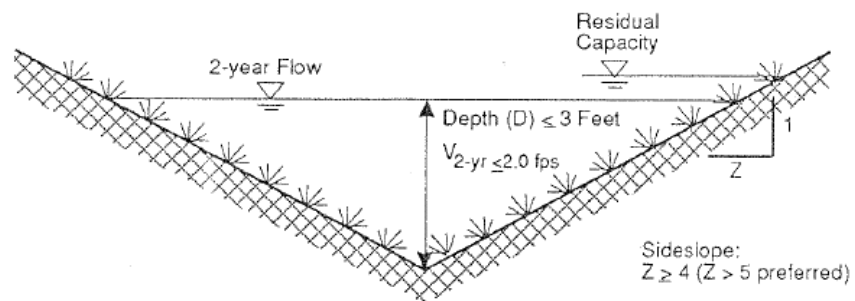
- a. Reliability and Consistency over Time
 - Dependent on proper design and maintenance
- b. Routine and Non-routine Maintenance
 - Routine maintenance; grass must be mowed, some litter removal, sediment removal to maintain channel flow capacity.
 - Non-routine maintenance: replacement of damaged grass.
- c. Sustainability of Maintenance or Program Management
 - Maintenance must be included in the budget to insure proper operation.



TRAPEZOIDAL GRASS-LINED SWALE SECTION
NOT TO SCALE



GRASS-LINED SWALE PROFILE
NOT TO SCALE



TRIANGULAR GRASS-LINED SWALE SECTION
NOT TO SCALE

Figure 8-9 Profile and Sections of a Grassed-Lined Swale

Source: Denver Urban Drainage and Flood Control District, 1992

8.3.4.5 Filter Strips And Flow Spreaders

Filter strips are vegetated areas designed to accept sheet flow provided by flow spreaders which accept flow from an upstream development. Vegetation may take the form of grasses, meadows, forests, etc. The primary mechanisms for pollutant removal are filtration, infiltration, and settling.

General applicability and experience with technique elsewhere

a. Typical Applications

- Filter strips can be used in residential and commercial sites, adjacent to impervious areas. Effectiveness depends on evenly distributed sheet flow, and limited drainage area and runoff volume. For grass filter strips, the environment must support turf-forming grasses. They have limited effectiveness in pollutant removal, and follow-up structural BMPs will still be required.

b. Design Considerations (See Figure 8-10 for representative schematic)

- The proper function of the flow spreader is key to the performance of the filter strip. If flow is allowed to concentrate, the bulk of the filter strip will be ineffective for pollutant removal and flow reduction. This will also result in erosion over time.
- Flow spreaders and filter strips should be limited to drainage areas of 5 acres or less.
- Channel grade for the last 20 feet of the dike or diversion entering the level spreader should be less than or equal to 1% and designed to provide a smooth transition into spreader.
- Grade of level spreader should be 0%.
- Depth of level spreader as measured from the lip should be at least 6 inches.
- Recommended length, width, and depth of flow spreader are presented in the following table:

Design Flow (cfs)	Entrance Width (ft)	Depth (ft)	End Width (ft)	Length (ft)
0 - 10	10	0.5	3	10
10 - 20	16	0.6	3	20
20 - 30	24	0.7	3	30

- Level spreader lip should be constructed on undisturbed soil (not fill material) to uniform height and zero grade over length of the spreader.
- Released runoff to outlet onto undisturbed stabilized areas in sheet flow and not allowed to reconcentrate below the structure.
- Slope (S_o) of filter strip from level spreader should not exceed 10 percent.
- The design width of the filter strip (W_G) should be the greater of the following: $W_G \geq 10$ feet or $W_G \geq 0.2L_i$, where L_i is the length of flow path of the sheet flow over the upstream impervious surface.
- Spreader lip to be protected with erosion resistant material, such as fiberglass matting or a rigid non-erodible material for higher flows, to prevent erosion and allow vegetation to be established.
- Wooded filter strips are preferred to gravel strips.

c. Other Experiences with BMP

- A Maryland study (Galli, 1992) of six grass filter systems showed that all filters were showing deterioration and decreased performance 1.3 to 2.6 years after installation. Low grass height was cited as the primary cause of decreased performance; the recommendation was that grass should be left as high as possible between mowings. Also, the invasion of annual grasses and weeds that experience seasonal die-back can greatly reduce filtering performance. It was concluded that all filters would fail within three years due to erosion from high runoff rates unless substantial repairs were made.

Reported pollutant removal efficiencies

- Filter strips must accept stormwater runoff as overland sheet flow in order to effectively filter suspended materials out of the overland flow.
- The removal of soluble pollutants is low because the degree of infiltration provided is generally very small.
- Removals of nutrients and oxygen demand decrease as the amount of clay in the soil increases.
- Reported data

20-Foot Wide Grassed Filter Strip (Taken from Schueler, 1987):

<u>Pollutant</u>	<u>Removal Rate (%)</u>
Total Phosphorus	10
Lead	30
BOD	10
Sediment	30
Total Nitrogen	10
COD	10
Copper	30
Zinc	30

100-Foot Wide Grassed Filter Strip (Taken from Schueler, 1987):

<u>Pollutant</u>	<u>Removal Rate (%)</u>
Total Phosphorus	50
Lead	90
BOD	70
Sediment	90
Total Nitrogen	50
COD	70
Copper	90
Zinc	90

Advantages

- Aesthetics of open, green space.
- Low cost, since developments are typically required to have open space in their plans
- Grasses and shrubs or trees provide wildlife habitat.

Disadvantages

- Human Risk, Public Safety and Potential Liability
 - Minimal
- Environmental Risk and Implications
 - The primary flood-control mechanism is infiltration; in areas of high ground water vulnerability, this may not be a good option.
- Other
 - On unstable slopes, soils or vegetation, rills and gullies may develop that negate the usefulness of the strips.
 - Excessive pedestrian or vehicle traffic may damage the vegetation and soils structure. The planting of shrubs and trees can help eliminate both of these disadvantages.
 - Inadequate maintenance of vegetation may result in partially denuded soils with predictable results in erosion, runoff quality and volume.